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SCIENTIFIC RESEARCH IN RELATION TO AGRICULTURAL PROBLEMS[1]

I AM proud of having an opportunity to assist at the birth of this new society. In this case it seems that parturition has been long overdue—perhaps owing to the size of the embryo, if one may judge by the secretary's statement of membership. At any rate it proves to be a very vigorous healthy youngster and since it will be watched over by all these experts in nutrition, diseases, etc., one can safely predict for it a rapid growth and active maturity.

I must ask you not to estimate my modesty by the title of my remarks, which appears on the program—"Scientific research in relation to agricultural problems." This very large subject has been assigned to me by your committee and one consents to discuss it on the present occasion only because the relationship of scientific research to the industries *in general* has recently been thoroughly discussed and forcibly brought home to every one. The relationship of scientific research to agriculture is only a particular phase of this general question which has been frequently and ably discussed from many quarters. It would serve no useful purpose to point out particular agricultural examples of principles which should be familiar to all scientists. It will, therefore, not be necessary to attempt a comprehensive treatment of the subject. It will be sufficient to point out certain respects in which the relationship is peculiarly important to agriculture, or in which agriculture differs from the other industries. In accordance with the desire of your committee, I shall speak largely from the standpoint of the so-called pure scientist.

Agricultural scientific research suffers more

[1] Address delivered at the organizing convention of the Canadian Society of Technical Agriculturists, Ottawa, June 3, 1920.

than does any other form of industrial research from a lack of realization on the part of the general public of its possibilities. This is due, I believe, to the familiarity on the part of the majority of people with agricultural operations. Any one will concede the value of research in relation to manufacturing industries involving chemical actions. The great majority of people are innocent of any knowledge of chemistry, and regard it as a highly complex, mysterious study capable of performing all sorts of wonders—in which opinion they are not discouraged by the chemists. But every one thinks he knows something of agriculture and many people think they are experts at it. To most people agriculture is simply taking a little care of plants and animals which would grow anyway. They can see no need of investigation in such familiar operations as ploughing, harrowing, harvesting and thrashing. And it is through average public opinion that the expensive support for research must be obtained. The head of an agricultural college informs us that it has just taken him three years to convince his board that a plant pathologist has any useful duties to perform.

Of course all technical agriculturists know that agriculture, like the other industries, has reached a stage at which little progress can be expected from casual observation or ordinary experience. Progress will result only from the careful application of scientific facts and principles which are known only to those who have been properly trained, or which have not yet been discovered. Agricultural problems are just as difficult and complex as those of any other industry. Our confidence that great progress will be made by the application of scientific principles in agriculture results from our knowledge of what has been accomplished in this way in the past. The achievements of agricultural scientific research in actual financial benefits to the country are not surpassed by those of any other industry. This is not the occasion, however, either to mention the problems which have been solved or to point out those which can be solved by the application of scientific principles. Owing to the fact that such a large proportion of our population must always be engaged in agriculture, any advance through scientific work must result in benefits which in the aggregate surpass those in other industries.

My second point is that technical research in agriculture involves research in an unusually wide range of basic subjects and that the technical researcher in agriculture is therefor peculiarly dependent on so-called pure science. Agricultural problems involve, among other things, the physics, chemistry, biology and geology of the soil, physiology of plants and animals (itself including many basic subjects), pathology of plants and animals, systematic biology, including entomology, foreign plant introduction, genetics, bacteriology, mechanics, climatology, sociology and economics. Many problems involve several of these subjects. There are, of course, routine problems such as testing varieties, rotations, etc.; which may involve little more than general agricultural knowledge. But the problems which will result in new departures of importance are likely to demand a profound knowledge of basic subjects. The big advances requiring only superficial science have mostly been made, and progress in future will depend more and more on profound study in more than one basic subject. The workers in these basic subjects supply the raw material—scientific information—which the technical agriculturists work up into manufactured articles—better agricultural practises. To sustain our metaphor further these manufactured articles are transported by the agricultural educationists to the consuming farmers.

Of course, as in other cases, the workers in these different fields ("fields" is surely a good word in an agricultural discussion) can not be sharply segregated. Many technical men engaged primarily in improving practises are also spreading information among the farmers; many of them are making discoveries in theoretical science. The same piece of work may involve both discovery and application. To use a simile from our own subject, the technical agriculturist may be considered a cross between the so-called pure scientist and the farmer. And as in Mendelian crosses, there

are degrees of dominance with respect to the contrasted characters of the parents. Sometimes the technical man is mostly pure farmer, sometimes mostly pure scientist, sometimes exactly intermediate. Not rarely the cross proves too wide and the offspring are completely sterile.

Owing to the unusually wide range of basic subjects this relationship of pure and applied science is peculiarly important in the case of agriculture. It is hopeless to expect a technical agriculturist to keep thoroughly posted in all the subjects ancillary to agriculture; it is equally hopeless to expect a worker in an ancillary science to keep posted on practical agriculture. There is need of special machinery to stimulate discoveries in those parts of the basic subjects related to agriculture and to provide for their immediate application.

The solution of this difficulty and others presently to be mentioned depends, in my opinion, on a large degree of organized cooperation in research. All the reasons in favor of cooperation in industrial research in general apply in the case of agriculture and these strong additional reasons.

The peculiar dependence of technical research in agriculture on research in a wide range of basic sciences demands cooperation between the pure scientist and the technical man. A technical agriculturist endeavoring to solve a practical problem is very likely to encounter a fundamental problem. A fundamental researcher is very likely to uncover a fact or principle which can be immediately applied—if he knows enough of the practical to make the application. Sometimes a technical man's duties and interests and training will permit him to follow up a fundamental lead. Sometimes a worker in a fundamental subject, may know enough of the practical and possess the inclination to make the application. But such cases are likely to be relatively rare. It seems obvious that the best results both from the practical and theoretical standpoints are to be obtained by close cooperation of all concerned. The practical man knows the problems and discovers where fundamental information is lacking in order to solve them. He can then enlist the services of the pure scientist in those problems which his duties, or training or interests will not permit him to attack. At the same time—and this is not the least important effect—theoretical science will be advanced. There will be a complex series of effects and counter-effects of the theoretical on the practical. It can not be too strongly emphasized that theoretical science receives as much from practical science as it gives to it. The theoretical advances made in practical research are as important as the practical advances made by the application of theoretical principles. And in agricultural problems the possibilities are particularly great.

I should like to refer to a particular example of what I have in mind. A very practical problem is the breeding of disease resistant plants. In the case of stem rust of wheat it turns out that the problem involves fundamental genetical work. But the prosecution of it requires a very substantial knowledge of plant pathology and its methods; it can be carried on best in collaboration with plant pathologists. Moreover it has recently given a very valuable lead in fundamental botany by showing the existence of many physiological and geographical races of rust which can be distinguished only by their virulence in particular varieties of wheat. Stakman and his collaborators have proven the existence of many of these geographical races in the Northern States and work at Saskatoon this year has demonstrated the existence of several scattered over western Canada, as well as the occasional occurrence of more than one race in the same locality. This discovery seems for the time to have made a practical solution impossible. But the point is that the geneticist and plant pathologist have had to collaborate on the problem and both have uncovered important leads for theoretical research. And before economic results are obtained the practical agronomist must be enlisted to test yields, earliness, etc. This investigation also shows the necessity of having the same work carried on concurrently at different places to meet varying local conditions.

Many of the most important problems in agriculture will in this way require the united efforts of several kinds of researchers. This must be true from the very nature of agricultural problems involving as they do a highly complex sort of conditions and a very wide range of basic subjects. Without cooperation we find the technical man necessarily spreading his efforts over so many subjects that he accomplishes little. This result is already too common. Without cooperation we find the pure scientist making foolish practical claims or helpless before an unusual practical situation. Nor will the best results be obtained when the cooperation consists of the fundamental scientists acting as chore boys for the technical men—performing their chemical analysis, physiological experiments or bacteriological identifications.

Apart from the need of workers of several kinds, many problems are so big that even where only one kind of researcher is necessary, several of these must collaborate if results are to be obtained in reasonable time. Again, in Canada local and environmental conditions are so highly varied that in the case of problems of nation-wide importance work must be carried on concurrently at many places.

With the argument that cooperation is necessary in order to avoid duplication of effort I have no great sympathy. We need both collaboration and duplication or collaboration *by* duplication. We all know of too many cases where claims have been made which have not been justified by the scientific work, which have injured scientific agriculture, and which would never have been made by several men working together. The cry of needless duplication of effort has been overdone; until agriculturists become infallible we can stand a great deal more duplication. It should, however, be deliberate duplication knowingly undertaken, not that of several men working in ignorance of each other's efforts.

That organized cooperation in research can accomplish a great deal when support is available, has been abundantly proven by the war experience of all nations.

In this society we have the machinery at hand to bring about the needed cooperation. This society will soon bring together all Canadian technical agriculturists and, I hope, all researchers in fundamental subjects whose work is in any way related to agriculture. Projects to be attacked can here be divided into phases and each man assigned the phase in which he is best qualified or most interested. Varying local conditions can be met by providing for the concurrent prosecution of similar work in different places. The groups must be democratically organized and cooperate freely; they can not function if one man assigns tasks to others. There is no need of entering into details at this time. They can be worked out to suit the problem.

Such a program will require frequent group meetings for consultation, formulating and modifying plans, reporting results, etc. These meetings can best be held in connection with the conventions of this society. On account of the great distances involved, it will be necessary that the institutions to which these men are attached should pay their travelling expenses. I believe that little difficulty will be encountered in this respect. Certainly these institutions could spend their money in no way which would be likely to yield more valuable results, not only in actual problems solved but also in keeping their staffs efficient.

That a program of consultation and collaboration will receive wide support is shown by the resolutions passed at the conference of deputy ministers of agriculture recently held at Ottawa. A resolution concerning experimental farms passed at that conference reads, in part, as follows:

> Be it resolved that . . . definite measures be adopted that will bring about greater cooperation in planning, conducting and giving publicity to the results of experimental farm work, to wit:
>
> (*a*) The formation of joint provincial advisory committees to be composed of representatives from the Dominian and provincial departments of agriculture. . . .
>
> (*b*) That such provincial committees shall meet not less than once annually to consider the results of experimental work . . . for the preceding year or years and to discuss and as far as may be pos-

sible recommend and approve contemplated lines of experimentation for ensuing years with a view to building up a system under which the work of the respective stations shall, as far as possible be supplementary to and correlated with each other. . . .

(c) That from time to time . . . conferences of these committees or representatives thereof from groups of provinces or all the provinces be held. . . .

Another resolution with respect to plant breeding reads, in part, as follows:

Be it resolved that plant breeding work in Canada whether carried on under federal or provincial direction should be fully coordinated and correlated by the holding of conferences of Canadian plant breeders . . . that the mode of extension (of plant breeding work) be arranged by conference from time to time between federal officers and the officers of the provinces concerned so as to avoid duplication of effort and attain the maximum degree of efficiency.

It is of course possible that local jealousies and personal affairs may interfere with the working out of such plans. I have heard of an institution where one kind of worker may study an insect so long as it remains in the air but as soon as it penetrates the hide of a cow he must not seek to follow it; it then becomes the property of a different subdepartment. If it digs into the ground another subdepartment claims it. I know that some technical agriculturists are constantly on the watch lest a botanist or chemist tread on their preserves, and that some pure scientists have "no trespassing" signs up for technical agriculturists. When members of the same department quarrel over such things we may expect trouble in a larger organization. The division of credit for work done may cause some heartburnings. But I believe the good sense of all concerned and the desire to get results will overcome all such difficulties. And a little experience in cooperative work will soon convince every one of the essential decency of scientific colleagues.

Such work need not interfere with any one's initiative, and no matter how much cooperation may be secured in solving practical problems, undoubtedly much of our progress will continue to depend on individual brains and initiative and imagination. Cooperation can not replace intellect but it can make intellect much more effective in solving certain kinds of problems.

Moreover it must be remembered that cooperation can be effective only with certain kinds of problems. The problems must be clean-cut, easily outlined. The end sought must already be perfectly clear; the probability of success must be demonstrable; the methods of attack must be fairly obvious from the data at hand. But there is another kind of studies—those which really open up new fields of interest and importance. These studies must be highly individual and do not lend themselves to cooperation. Such problems can not be outlined because they are not known or are perceived only vaguely. One gets a hint but the end of the trail is not clear; the success of the work is doubtful or may appear ridiculous. The project can not be outlined so clearly and attractively as to enlist the help of colleagues or the support of executive boards which control funds.

And just here, it may be remarked, is a defect inherent in all institutions and organizations whose specific purpose is the carrying on or support of research. The directors or chiefs can not give financial support unless the problem can be clearly outlined, and the probability of its solution demonstrated. They must thereby exclude many of that second and higher type of researches to which I have referred. If Mendel had had to ask the prelate of his monastery for land and labor to carry on his experiments, he could not have justified his request by predicting the discovery of his law of heredity. There is after all some advantage in holding a teaching position in which one can potter at whatever notions one conceives without having to justify them to some one controlling his salary and without having to give reports at intervals. We teachers are not as envious of you full-time research men in governmental positions as you might suppose.

For the same reason it would, in my opinion, be a mistake to do anything that would tend to concentrate research in governmental departments or institutions. Every teacher

should be encouraged to work at whatever problems he wishes to attack. When a man's teaching or other duties are sufficient to justify maintaining him and yet leave him time for research he is more likely to choose problems which break new ground than if every research has to be justified even for the reason that he is paid a salary for research.

There must in general be no restriction on a man's choice of problems or on the distance to which he may follow a research lead. For this reason I must object to the suggestion made to-day that provincial men confine themselves to problems of provincial importance and that problems of wider significance be reserved for the Dominion Department of Agriculture. One never knows where a trail is going to lead—that is one of the chief attractions in investigation work. If a worker in Saskatchewan uncovers a trail which leads over in Manitoba or Ontario or the States, he won't stop at the boundary. The wider its significance the harder he will follow it. Our most important provincial problems are of equal importance outside provincial boundaries. You can not say to a provincial man "You may study these little local questions, but you must leave the big things to the Dominion men at Ottawa." Only a very mediocre set of men would endure such a restriction.

Apart from helping by cooperation in the solution of practical agricultural problems, the worker in a basic subject can do a great deal by a judicious choice of problems and materials. A geneticist or plant physiologist for example in attacking a fundamental problem can use a crop plant of great economic value just as well as the usual greenhouse plants. At the same time he is likely to reveal, perhaps incidentally, perhaps directly, information of great practical importance concerning this plant. Our scientific men could attack these problems on the borderline between the theoretical and the practical. They could attack a practical problem not only for its own sake but in the full expectation of uncovering a theoretical lead. In many cases in the past they have not attacked practical or semi-practical problems partly because of ignorance concerning them, partly for fear of offending technical colleagues.

Another difference between research in agriculture and that in the other industries concerns the remuneration of the workers. The industrial research man shares, in part at least, in the financial benefits which accrue from his work. Great increase in wealth results from the perfection of a technical invention. Even if the researcher is a hired employee of a corporation he shares handsomely in the benefit. The industrial researcher therefore always feels the powerful financial stimulus.

The agricultural researcher, on the other hand, deliberately renounces all such rewards. In that respect he is like the pure scientist. Though his work may result in great financial benefit to his country, he knows that he will profit not at all or very slightly. From the nature of his work he must be attached to governmental or educational institutions, and he knows that the salaries in such positions can never be very large. But when for the sake of his work he renounces hope of becoming wealthy, he can surely expect a reasonable salary. If good researchers are to be retained in and attracted to agricultural work, the remuneration must be sufficient, not to compete with what other industries offer to research men, but to make possible comfortable habits of life. Our standard joke concerning the salaries of teachers is unfortunately just as applicable to positions in which the teachers are also researchers and to those in which research only is carried on.

There is another aspect of the relationship between scientific research and Canadian agricultural problems to which I must refer, namely, the educational aspect. It should be perfectly clear that the men who are to do worth-while investigational work in agricultural problems must have a thorough training in the basic subjects as well as a broad education in the languages and humanities. As I have already pointed out, a thorough understanding of agricultural questions demands a peculiarly broad acquaintance with many fundamental subjects. The problems of agriculture involve just as complex scientific con-

ditions as do those of medicine or engineering for example. And the men who are to solve them must have just as broad and thorough a fundamental training as the researcher in medicine or engineering. Moreover, apart from his research, the technical agriculturist has to face just as many situations requiring broad education and culture as have any other professional men.

Now the medical colleges require the equivalent of two years of arts work with specified large credits in the sciences, before admission is granted to the purely medical studies. Some indeed require full arts graduation and all medical authorities advise graduation in arts even where they do not require it. All this is required of those who are to become only general medical practitioners. Much more is necessary for the research man.

Similar conditions are found in regard to the training for other professions. In engineering, law, divinity, a broad fundamental training is considered necessary and is generally required. At the recent Canadian universities conference held at Quebec a resolution was unanimously adopted calling for large increases in English, history, economics and particularly fundamental science in the training of engineers. The ideal of all educationists in these professions is to secure complete arts graduation before admission to professional studies, and failing that a large and specified amount of arts work.

In my opinion the professional agriculturist should have just as thorough a pre-professional training. This is true not only for the researcher in agricultural problems but also for agricultural teachers in schools or colleges, district representatives, inspectors, laboratory men and various administrators.

In those institutions which include both arts and agricultural colleges, it should be easy to arrange for such training. The pre-agricultural students should be taught in the same classes as the pre-medical students, or pre-engineering students, or straight arts students. In other places the students may not be given the formal arts classes but he should get the equivalent of them in a thorough broad training during the first two years. In all cases, if he is to benefit by his work, complete matriculation should be demanded before the student is permitted to enter. It is essential pedagogically that the basic subjects be taught before the student takes up the professional ones. They should certainly not be tacked on after the student has taken his professional work. This will involve an almost complete separation of the courses for technical agriculturists from those for the men who are to return to the farms. In short our ideal should be to bring our professional agricultural training abreast of our training for other professions by requiring as pre-agricultural study a large amount of, and as soon as possible complete, arts work. Only in this way can we secure a supply of properly trained research men as well as of other technical agriculturists.

The educational aspect of the relationship also involves the question of graduate work which is a very passing one in Canada. But as that is to be dealt with by another speaker, I shall refrain from discussing it.

I said at the outset that I would not attempt a comprehensive treatment of the subject—in spite of the time I have taken. I have tried to emphasize four respects in which, in my opinion, the relation of scientific research to agriculture is peculiarly important in Canada at the present time. They may be designated (1) Foundation, (2) Cooperation, (3) Remuneration and (4) Education.

W. P. THOMPSON
UNIVERSITY OF SASKATCHEWAN

LIMITATIONS OF EXPERIMENT IN EXPLAINING NATURAL HABIT, AS ILLUSTRATED BY THE DIURNAL MIGRATION[1]

THE general facts about the diurnal distribution of plankton organisms are these: at night there is greater abundance of a given species at higher levels and less abundance at

[1] A paper read at the meeting of the Western Society of Naturalists, Pasadena, California, June 20, 1919.